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Atomic Oxygen Exposure of Polyimide Foam for *International Space Station* Solar Array Wing Blanket Box

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LIST OF ACRONYMS AND SYMBOLS

AO	atomic oxygen
AOBF	Atomic Oxygen Beam Facility
<i>ISS</i>	<i>International Space Station</i>
MSFC	Marshall Space Flight Center
SEM	scanning electron microscope
UV	ultraviolet

TECHNICAL MEMORANDUM

ATOMIC OXYGEN EXPOSURE OF POLYIMIDE FOAM FOR *INTERNATIONAL SPACE STATION* SOLAR ARRAY WING BLANKET BOX

1. INTRODUCTION

Solar arrays were delivered to the *International Space Station (ISS)* and deployed during Flight 4A in November 2000. Photographs taken during Shuttle rendezvous and flyarounds have shown severe degradation of the aluminized DuPont® Kapton® film cover of the solar array wing blanket box (fig. 1). This was first observed with Flight 5A in February 2001 and confirmed during subsequent flights as cited in “Solar Array Wing Box Foam Pad Degradation,” a memo by Carlos Soares of The Boeing Company, dated December 16, 2002. The solar array wing blanket box has a polyimide foam pad that is now exposed to the space environment and is being eroded by atomic oxygen (AO).

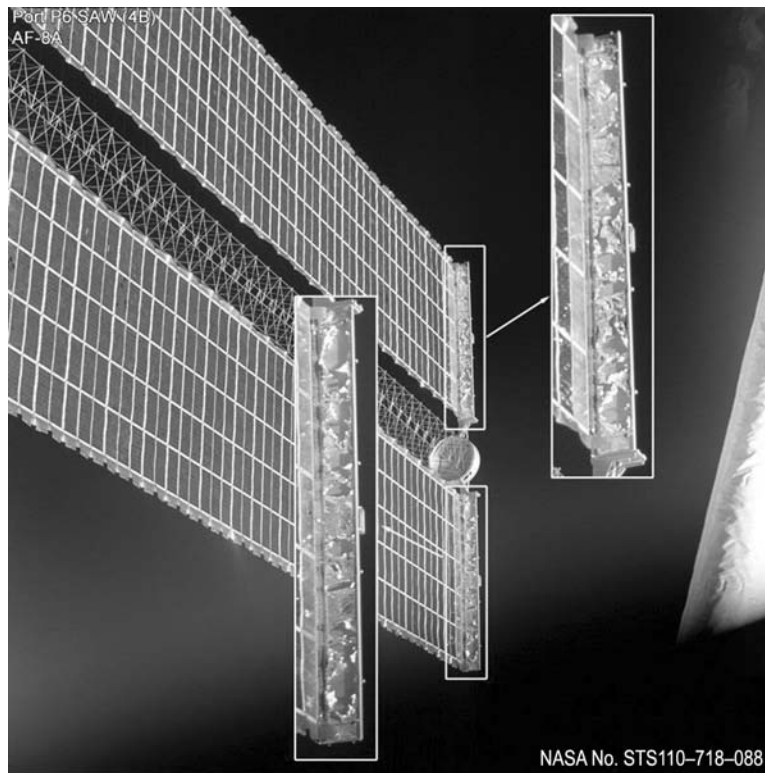


Figure 1. Degradation of aluminized Kapton cover of solar array wing blanket box, exposing foam to space environment (photo courtesy of Johnson Space Center).

The primary purpose of the foam pad in the solar array wing blanket box was to protect the solar cells from vibration damage during launch. Erosion of the polyimide foam raised concerns about particulate generation. According to SSP 30426, Space Station External Contamination Control Requirements, section 3.4.2, the external contamination control requirements for *ISS* limit the release of particulates to one particle 100 μm or larger per orbit per 1×10^{-5} steradian field of view, as seen by a 1-m-diameter aperture telescope.

Another concern was the structural integrity of the foam. The solar array wing on the P6 truss is to be retracted during Flight 12A.1. During Flight 13A, it will be moved from the Z1 truss to the end of the P5 truss and redeployed. If the foam cracks or is crushed during retraction, additional particulate could be generated, including large pieces of debris.

The purpose of this test was to determine the magnitude of particulate generation caused by low-Earth orbital environment exposure of the foam and also by compression of the foam during simulated solar array wing retraction. The total fluence for this test was 5.8×10^{21} atoms/cm², approximately equivalent to 22 mo onorbit. This was the estimated time between Flights 5A and 12A, prior to the hold on Shuttle flights in February 2003.

2. TEST SETUP

Marshall Space Flight Center (MSFC) received a large sample of polyimide foam material identical to that used in the *ISS* solar array wing blanket box foam pad assembly. The foam provided was 0.5 in (1.27 cm) thick. A test article 1.5 in (3.8 cm) wide by 4 in (10.2 cm) long was cut out, photographed, and weighed. Because polyimide is known to be hygroscopic, the sample was placed in a vacuum chamber and pumped down to 50 mtorr. The sample was then quickly removed from the vacuum chamber and placed on a Mettler AT260 balance, and the time was noted. Mass of the sample was recorded over 5 min, and the zero time mass was calculated using linear regression. This technique eliminates weight uncertainty due to changing humidity.

The foam sample was then exposed to 5.8×10^{21} atoms/cm² AO of 5-eV energy in MSFC's Atomic Oxygen Beam Facility (AOBF), with the AO path normal to the foam surface. Exposure was interrupted at 1.5×10^{21} , 3.3×10^{21} , and 5×10^{21} atoms/cm² to change out the strip of Kapton used to monitor the AO fluence. (Beam current is monitored throughout the test to determine fluence, checked by a Kapton sample's mass loss and known AO reactivity.) At each interruption, the sample was photographed and weighed, and a catch plate in the bottom of the chamber was monitored for particulate fallout. Microscopic inspection of the particulate led to the placement of a second Kapton witness sample in the bottom of the chamber. Mass loss of this Kapton sample indicates that scattered AO was also eroding any foam particle fallout.

During production of the AO plasma, ultraviolet (UV) radiation is produced in the AOBF, primarily at 130 nm, the AO resonant peak in the vacuum UV region. The foam sample was exposed to $\approx 9,260$ equivalent Sun hours of vacuum UV radiation during this test.

Following AO exposure, the foam sample was photographed using a scanning electron microscope (SEM). SEM photographs were also taken of a control sample of foam.

Following SEM photography, a 1- by 1.5-in (2.54- by 3.8-cm) section was cut off for determining the AO erosion profile. The remainder of the foam sample was compressed with a load of 2.5 psi. Particulate generation due to compression was negligible.

3. TEST RESULTS

3.1 Mass Loss

Figure 2 shows the mass of the foam sample versus AO fluence. The exposure of 5.8×10^{21} atoms/cm² eroded about one-third of the sample. It was calculated that 1.7×10^{22} atoms/cm² would be needed to entirely erode away the sample, using the following curve fit:

$$\text{Sample mass} = 1.751 - (1.03 \times 10^{-22} \times \text{fluence}) , \quad (1)$$

where sample mass is measured in grams, and fluence is measured in atoms/cm².

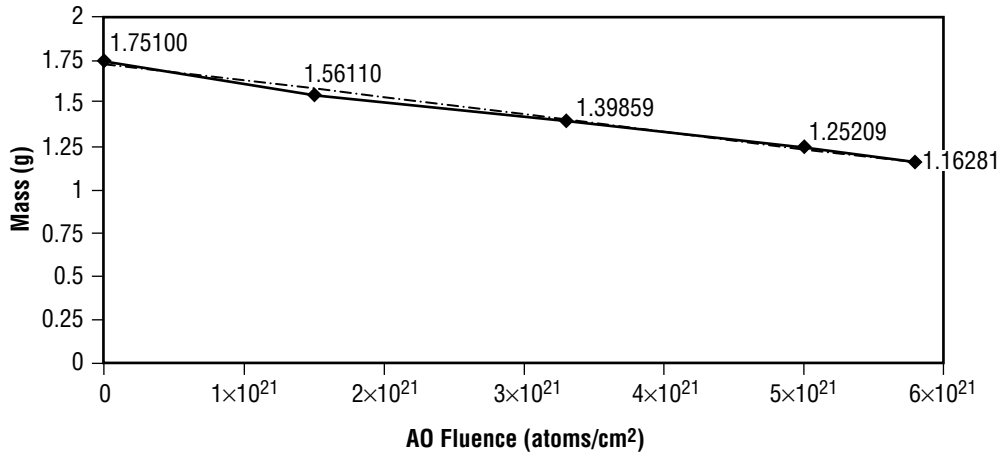


Figure 2. Mass loss of solar array wing foam as a function of AO fluence.

3.2 Thickness Loss

The original thickness of the foam sample was 0.5 in (1.27 cm). After AO exposure, it was 0.32 in (0.81 cm) thick in the center. The thickness loss is not uniform across the sample because the AOBFB beam is not uniform. The 1- by 1.5-in section of foam was examined under a microscope, which showed that AO erosion is limited to the surface. Figure 3 is a comparison of the exposed foam sample to the control foam, showing the thickness loss and change in appearance.

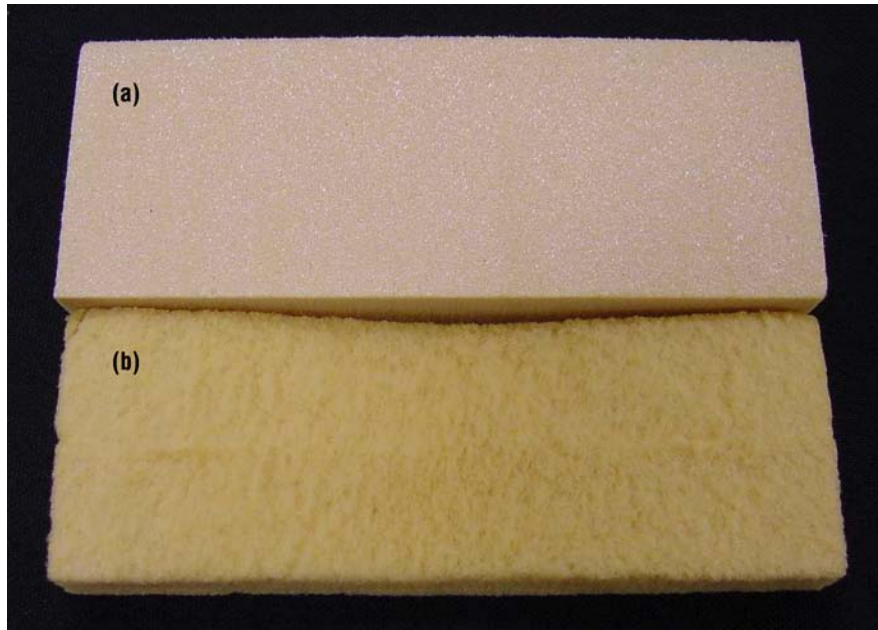


Figure 3. Polyimide foam samples: (a) control and (b) AO exposed.

3.3 Particulate Fallout

A catch plate in the bottom of the AOBF was used to monitor particulate fallout. These particles were examined under a microscope using $\times 120$ magnification to separate foam material from particles generated by the AOBF itself (neutralizer plate, etc.). Microscopy also showed that scattered AO was eroding particles on the catch plate. A Kapton sample placed on the catch plate indicated erosion equivalent to 1 percent of the total fluence. After the first particulate analysis was complete, it was decided to try a second collection of particles by tapping the foam sample over a collector plate. This generated a few more particles for analysis but not very many. Figure 4 shows the total number of particles counted at each interval of the test, the minimum and maximum size particle observed, and the average particle size during AO exposure.

3.4 Scanning Electron Microscope Analysis

After the AO exposure was complete, SEM photography was performed. Figure 5 shows a control sample; figure 6 is the exposed foam. In general, the control sample had closed bubbles of foam, while bubbles were hard to discern in the AO-exposed foam. The surface of the AO-exposed foam could be described as wispy or fuzzy.

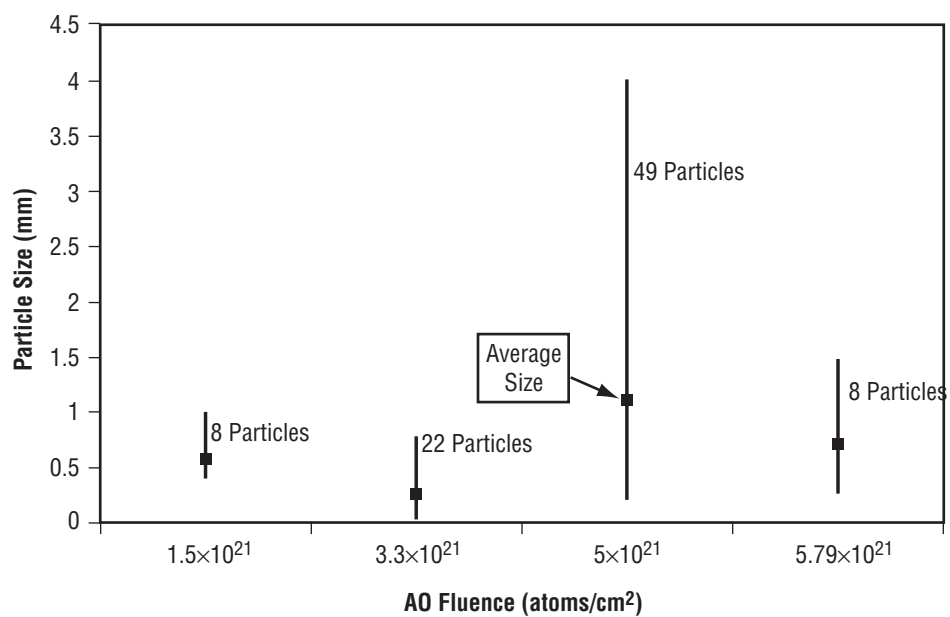


Figure 4. Minimum, average, and maximum particle size with total number of particles captured at each test interval.

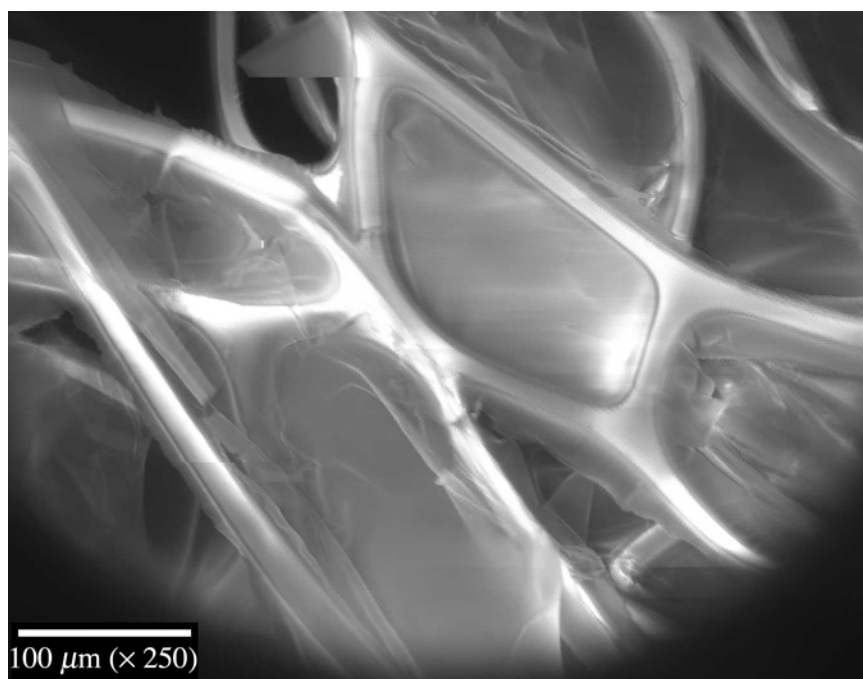


Figure 5. SEM photograph of control sample of foam.

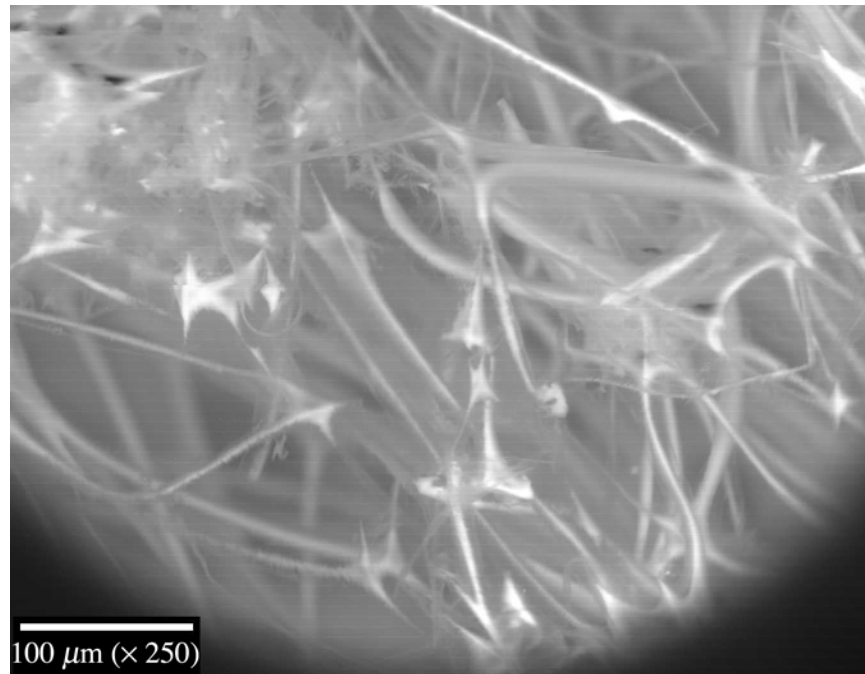


Figure 6. SEM photograph of AO-exposed foam.

3.5 Compression Test

The sample was placed in a plastic bag to retain any particles and held between two 6- by 6-in (15.2- by 15.2-cm) aluminum plates. The requested compression load was 2.5 psi, which was 11.25 lb for the foam sample after sectioning. The weight of the top aluminum plate was included in the load calculation. The compression load was applied at a rate of 15 lb/min, held for 1 min, and then released. The travel distance of the load head for this test was 0.14 in (0.36 cm) for the AO-exposed sample and 0.09 in (0.23 cm) for a control sample. The difference in travel distance is due to the eroded face of the sample and the height difference across the length. Due to the varied thickness of the foam sample, compression of the AO-exposed foam at the edges would be greater than the same area of the control sample. No significant particulate was noted for either sample after the test.

4. CONCLUSIONS

The polyimide foam used in the *ISS* solar array wing blanket box assembly is susceptible to significant AO erosion. The foam sample in this test lost one-third of its mass after exposure to the equivalent of 22 mo onorbit. Some particulate was generated by exposure to simulated orbital conditions and the simulated solar array retraction (compression test). However, onorbit, these particles would also be eroded by AO. The captured particles were generally <1 mm, and the particles shaken free of the sample had a maximum size of 4 mm. SEM imagery did not reveal anything unexpected. The foam sample maintained integrity after a compression load of 2.5 psi.

There was some concern over accuracy of the data with only one foam sample, even though there was a series of exposures where the mass loss followed a predictable trend. A survey of earlier AO tests of polyimide foam in the MSFC AOBF revealed Willmid™ CP50 from Illbruck and Claremont Low K 200. The Willmid lost 2.63 mg/cm² per 1×10^{21} atoms/cm² of AO, and the Claremont lost 2.79 mg/cm² per 1×10^{21} atoms/cm² of AO. By comparison, this sample averaged 2.62 mg/cm² lost per 1×10^{21} atoms/cm² of AO. A later exposure of the same solar array wing foam from a different batch averaged a mass loss of 2.66 mg/cm² per 1×10^{21} atoms/cm². (Minimal particulate fallout was observed.) This normalized mass loss gives us increased confidence in our simulation of AO erosion.

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